Per-parcel land use classification in urban areas applying a rule-based technique

ABSTRACT

Monitoring urban land use requires very high spatial resolution image data, acquired either by airborne or spaceborne sensor systems. The information content of such images is very complex, thus information extraction is currently performed on the basis of visual interpretation. The aim of the research described in this study is to formalise the visual interpretation procedure in order to automate the land use mapping process for urban areas. The assumption underlying this approach is that the land use functions can be distinguished on the basis of the differences in spatial distribution and pattern of land cover forms. IKONOS data covering a part of the metropolitan area of Vienna, Austria, are used in this study.

ZUSAMMENFASSUNG

Regelbasierte Auswertemethoden zur Landnutzungsklassifikation auf Parzellenebene in urbanen Räumen

Der Einsatz von Fernerkundung zur Erfassung von Landnutzung in Stadtgebieten erfordert sehr hochauflösende Daten, die entweder von flugzeuggetragenen Sensoren oder von Satellitensystemen stammen. Auf Grund des hohen Informationsgehaltes und der Komplexität solcher Daten erfolgt die Auswertung zur Zeit vorwiegend auf Basis visueller Interpretationen. Das Ziel der in diesem Beitrag vorgestellten Forschungsarbeit ist die Formalisierung der visuellen Interpretation, als Voraussetzung für eine automatische Landnutzungskartierung. Dabei wird von der Annahme ausgegangen, dass verschiedene Arten der Landnutzung anhand spezifischer Objektstrukturen unterschieden werden können. Für die Untersuchungen werden IKONOS-Daten aus dem Stadtgebiet von Wien verwendet.

Mag. Thomas Bauer

ist Doktorand (Fernerkundung)/PhD-Student (Remote Sensing)
Adresse: Geschäftsfeld Umweltplanung/ Environmental Planning Department, Austrian Research Centers Seibersdorf, A-2444 Seibersdorf
Tel.: +43 50 5 50–38 70
Fax: +43 50 5 50–38 88
E-Mail: thomas.bauer@arcs.ac.at

Dr. Klaus Steinnocher

ist Projektmanager Fernerkundung/ Project Manager Remote Sensing
Adresse: Geschäftsfeld Umweltplanung/ Environmental Planning Department, Austrian Research Centers Seibersdorf, A-2444 Seibersdorf
Tel.: +43 50 5 50–38 76
Fax: +43 50 5 50–38 88
E-Mail: klaus.steinnocher@arcs.ac.at

1 Introduction

The main objective of satellite image processing for planning purposes is land use classification. The availability of satellite-based land use maps, generally improved with ancillary data, constitutes a starting point for many applications in different domains of spatial planning (Donnay 1999). Many European cities are experiencing considerable residential development pressure, due to increasing populations or a higher demand on living standards. One consequence of such developments is that urban areas are dynamic environments which are strongly involved in an inter-urban land use pattern change. In order for city planners to develop cohesive policies which take these changes into account, they require regular, up to date and consistent information.

The traditional method to get information on land use is based on the visual interpretation of very high resolution aerial photographs; a process, which is expensive and time consuming. High resolution satellite data will be an alternative for updating and maintaining cartographic and geographic databases. Advanced sensors such as IKONOS with a spatial resolution of less than 5 meters even in multispectral mode, will offer for the first time the potential to map urban areas at a spatial scale previously unattainable with satellite imagery (Ridley et al. 1997, Jensen & Cowen 1999).

Most of the applications in image processing still rely on concepts developed in the early 70s and it is argued that they do not make use of spatial concepts (Blaschke et al. 2000). While many studies have managed to derive broad land use types present in urban areas (e.g., residential, commercial, open spaces), difficulties were encountered when trying to accurately and precisely characterise the complex intra-urban patterns (e.g., distinguishing between different densities and patterns of residential land use) (Fung & Chan 1994, Johnsson 1994). If the full potential of the new image data sets for urban land use mapping is to be realised, new inferential remote-sensing analysis tools need to be applied. This is because urban land use is an abstract concept – an amalgam of social, economic and environmental factors – one that is defined in terms of function rather than form. Thus the relationship between land use in urban areas and spectral responses recorded in images is very complex and indirect, precluding the use of traditional classification approaches (e.g., Fung & Chan 1994, Johnsson 1994, Barr & Barnsley 1997). In such cases, an alternative is to utilise a two stage approach for processing. In the first stage, the principal land cover types present in the scene are derived. In the second stage, this information is analysed in a spatial context in order to distinguish between the different land uses present.

A prerequisite for the realisation of this approach is the extraction and classification of image objects. Early investigations found that the quality of morphological properties and spatial relations of image objects depend significantly on the accuracy of the initial land cover classification (Barnsley & Barr 1997, Bauer et al. 1999). In particular, it was found that the land cover classification of very high spatial resolution images resulted in a complex structural composition, which might inhibit the recognition of distinct urban land use categories. As studies have proven, high resolution of the data does not automatically lead to higher classification accuracy. This is due to the heterogeneity of objects within an urban area which leads to either misclassified pixels or unwanted details (Woodcock & Strahler 1987, Donnay 1999).

2 Data and methodology

The investigations presented in this paper are based on multispectral and panchromatic data of the IKONOS satellite, covering a part of the metropolitan area of Vienna. The corresponding land use inventory of the City Council of Vienna is used as reference.

The morphological properties and spatial patterns of the land cover objects are analysed with the Structural Analysing and Mapping System (SAMS) leading to a characterisation and description of distinct urban land use categories (Barr & Barnsley 1997). This analysis is carried out on the basis of parcels as defined within the land use inventory mentioned above. Thus the term "per-parcel land use classification“ is used. The resulting information is integrated in a rule system and implemented with the software tool eCognition (Baatz et al. 2000). This object-oriented classifier applies the rules to the land cover objects resulting in the required land use map. The assumption underlying this approach is that the land use functions (i.e., different densities of residential development, along with areas of commercial and industrial activity) can be distinguished on the basis of the differences in spatial distribution and pattern of land cover forms.

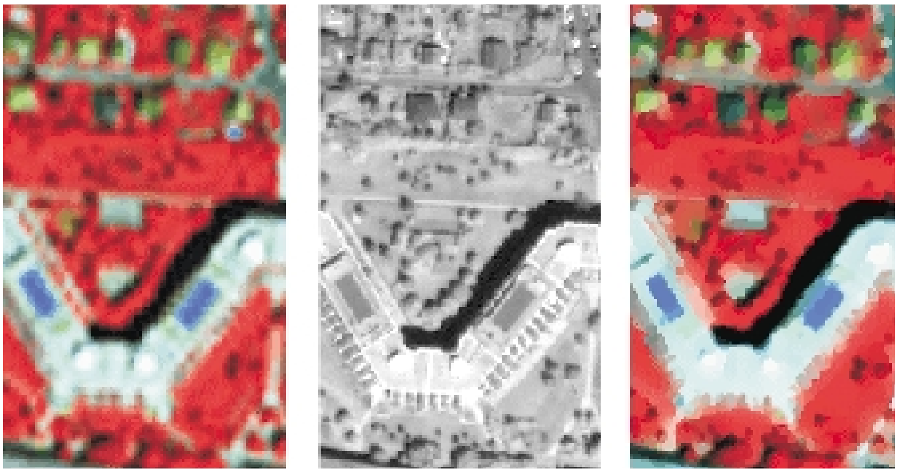

Fig. 1: Adaptive Image Fusion (multispectral – panchromatic – fusion)

3 Image pre-processing

IKONOS provides both multispectral and panchromatic data with a spatial resolution of 4 and 1 m respectively. In order to benefit from the multispectral information and the very high resolution of the panchromatic image adaptive image fusion (AIF) was applied to the IKONOS scene. AIF sharpens the low spatial resolution image according to object edges found in the higher spatial resolution image. In contrast to other methods AIF preserves the spectral characteristics of the original low resolution image to a high extent. The process could be described as sigma filtering of the multispectral band where the filter behaviour is controlled by the panchromatic image (Steinnocher 1999). This leads to a pre-segmentation of the original image. The result is an artificial multispectral image stack with the spatial resolution of the panchromatic image. *Figure 1* shows the original multispectral image, the panchromatic band and the resulting fusion image (from left to right). It can be seen that the fused image is sharper compared to the original multispectral image, contains fewer single pixel objects and that the variance within objects is lower.

4 Mapping land cover objects

A variety of techniques are available for discriminating the basic entities of an urban scene (buildings, roads, open spaces) starting from unsupervised per-pixel classifiers to sophisticated segmentation algorithms, such as region growing or split-and-merge procedures, which take the neighbouring pixels into account. An overview about the recent developments in the field of image segmentation is given by Blaschke et al. (2000).

Conventional supervised classification techniques are poor at discriminating between urban land use categories but they still supply reliable results for mapping the required land cover objects within the scene. In this study a supervised maximum-likelihood classifier (ML) was chosen as it provides good results in a heterogeneous urban area and allows control over the number and nature of the desired classes. Problems arise when the spectral signatures of two classes are similar. As this is the case for built areas and roads, which are key entities for further processing, a GIS layer containing the road-network was applied as a mask. Another disadvantage of a ML classification is the "salt-and-pepper“ effect in the output image. In order to reduce the number of artefacts the AIF method was applied for image pre-processing and the result is a land cover image with predominantly homogenous objects.

5 Analysing the structural composition of land use

The analysis of the structures within the initial land cover classification provides information which can be used for building a rule base for the final land use classification. Therefore the Structural Analysing and Mapping System (SAMS) was applied. SAMS is a region-based structural analysis system which operates on an initial land cover classification of a multispectral image (Barnsley & Barr 1997). In SAMS, contiguous blocks of pixels with the same label are aggregated to discrete land cover objects. Thereafter, the system processes the derived objects in order to compile a structural description of their morphological properties (e.g., area, compactness), as well as the spatial relations that exist between them (e.g., adjacency, containment).

The derived structural information is represented and encoded in a graph-theoretic data model known as XRAG (eXtended Relational Attribute Graph). In the XRAG model, each land cover object is represented as a graph node, while the existence of a relationship between any two land cover objects for a given spatial relation (e.g., adjacency) is indicated by a connecting edge between the corresponding nodes. The derived morphological properties for an object are expressed as attributes of the corresponding node in the XRAG model. A full and detailed description of the XRAG model is provided in Barr & Barnsley (1997).

In *figure 2* a subset of the land cover map representing a residential area is shown together with its adjacency graph. The corresponding tables with information about the images objects and the spatial relation "adjacency" are presented as well. More than 30 land use parcels were selected and analysed in this manner to gather information about the specific parameters for urban land use classes. These investigations have shown that in this way typical features which describe land use categories can be identified. Problems occur when land use classes are to be distinguished, which are similar in structure and land cover composition but differ in their functional characteristics (e.g., detecting a school within a residential area). These restrictions have to be taken into consideration when building up the rule base.

6 Rule-based land use classification

The rule-based land use classification was performed with the software tool eCognition which follows an object-oriented concept. It is one of the first commercially available software systems of this type featuring many essential tools for automated image analysis relying on image objects. The software provides tools for object-oriented fuzzy-rule classification including contextual and shape information, and allows to express concepts and knowledge about the relevant image content. The basic idea of eCognition is that important semantic information necessary to interpret an image is not represented in single pixels, but in meaningful image objects and their mutual relationships (Baatz et al. 2000).

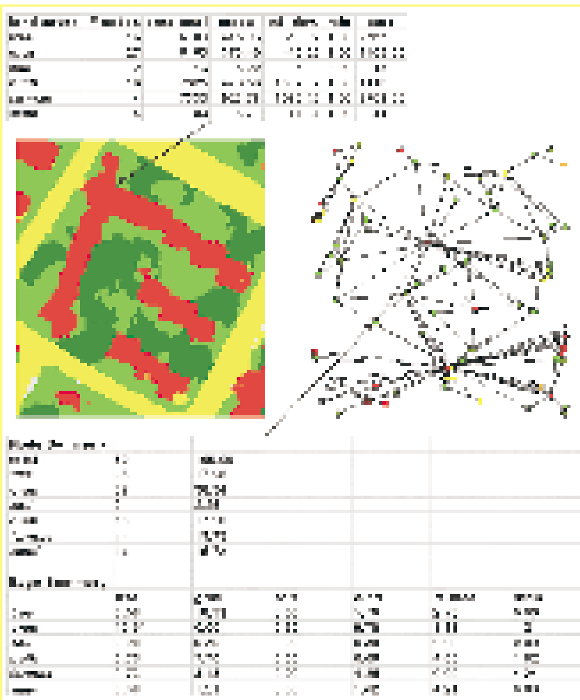

Fig. 2: Analysing urban structures – example of a residential area

A segmentation technique is used to build up a hierarchical network of image objects. Hence, each image object "knows“ its neighbouring objects and it is possible to define relations between these objects. This is done within a class hierarchy which is the frame for formulating the knowledge base for the classification process. Membership functions are used to produce class description which consists of a set of fuzzy expressions allowing the evaluation of specific features and their logical operation. Fuzzy algebra is used as a classification technique which translates feature values into fuzzy values between 0 and 1. In the class hierarchy different image objects can be aggregated into groups. In this study the classification process is focused on the features area, relative border length to (adjacency) and number of neighbours to define the rules. A full description of the concept and the available functions of this software is given by Baatz et al. (2000).

The objective of the case study is to derive land use classes as defined by the land use inventory of the City Council of Vienna. This nomenclature comprises 42 classes based mainly on land use function. As a result of the previous analysis of urban structures only those classes were selected which were separable on a structural basis. The borders of single land use parcels were defined by integrating the polygons from the land use inventory into the classification process.

In a first step the initial land cover objects were classified based on the feature area (small – medium – large). Taking into account the results of the structural analysis a basic composition of land cover objects was defined for each land use class. In case of residential areas this composition consists of a large built area which is adjacent to either a medium grass or a medium tree area. In contrast an industrial or commercial area can be defined by large built-up and large paved areas which are adjacent to each other. In a second step neighbouring objects are allocated to these composite areas dependent on the degree of their adjacency. In some cases this relationship might be ambiguous, i.e., more than one land use is found within a parcel. This problem is solved by determining the dominant pattern within the pre-defined land use parcels.

The resulting land use map is shown in *figure 3*. Eleven classes could be identified based on the structural composition of land cover objects. Compared to the land use inventory of the city council of Vienna a high degree of correspondence was found for those classes which are not determined solely on their function. However, problems might occur where the structures of classes are similar; e.g., residential areas with garden and allotment gardens, both consisting of a high percentage of vegetation and a large number of differently sized houses. The differentiation of the two classes depends mainly on the size of the houses. This example illustrates that the quality of the land use classification strongly relies on the initial segmentation and classification of the image objects because some rules are sensitive to slight differences in the parameters (e.g., size of houses).

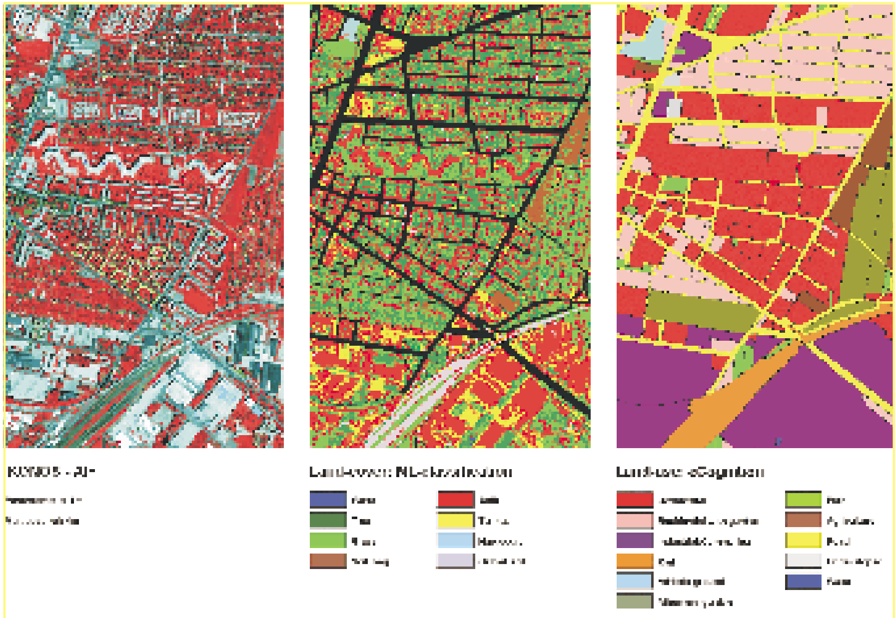

Fig. 3: Land cover mapping and subsequent rule- and object-oriented land use classification

7 Conclusion

A first conclusion to be drawn from the study is the suitability of IKONOS-data for urban land use mapping, thus representing an alternative to aerial photographs for updating and maintaining cartographic and geographic databases.

The two step approach – mapping land cover objects and subsequently classifying the structural composition of these objects – proved to be feasible for deriving urban land use classes. The essential step in this process is the transition from the spatial distribution of land cover objects to land use entities, which was formalised in a set of rules. This rule base was implemented in eCognition and used for an object-oriented land use classification.

A prerequisite for the definition of rules is an analysis of the structural composition of different land use categories. For this task SAMS turned out to be a valuable tool allowing the characterisation and description of distinct urban land use categories. As an empirical analysis tool it was found to be an ideal supplement to eCognition.

Experiments with the object-oriented classification algorithm have shown that the quality of the initial land cover map has a strong impact on the resulting land use classification. The better the single objects are defined in the land cover map, the better will be the resulting land use information. When conventional per-pixel classification methods are applied, pre-processing is required to avoid "salt-and-pepper“ effects and reduce the number of objects in the scene. The AIF is an effective tool for this purpose as it not only allows the combination of the higher resolution panchromatic and the multispectral images acquired by the new commercial satellites, but also leads to a pre-segmentation of the fused image.

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